height. From Nausett Lights to High Head much of the cape, as it originally was, has been demolished, and the process is still going forward; but the sea restores a part of what it takes, forming this curved bank of sand, five miles long and one to three miles wide, which encloses the deep and commodious harbor of Provincetown. The section here, to a depth of one hundred and eighty-two feet, was shown by a boring made some twenty years ago at the end of Central wharf. Sand extended from low tide line for thirty-five feet, below which interstratified sand and fine gravel continued to one hundred and seventy feet, where the first clay was encountered. This was dark-colored and very compact, extending twelve feet, at which depth it was not penetrated. Shells of *Scapharca transversa*, *Ostrea virginiana* (at one hundred and twenty feet), *Lunatia heros* and others were found to the depth of at least one hundred and forty feet. Successive generations of these inhabitants of the sea have been buried during this accumulation of its detritus, and at the same time its waters have probably been gradually rising upon the land.

The height of the principal hills of this town, as determined by Major Graham of the Coast Survey, are as follows: Mt. Ararat, one hundred feet above mean low tide; Mt. Gilboa, one hundred and six; Oak Head, one hundred and four; Miller's hill, eighty-nine; High Pole hill, one hundred; Telegraph hill, ninety-eight; Creek hill, eighty-four. These are dunes on the harbor side which have mostly become covered with bushes and trees. Others of nearly equal height, occupying the side next to the ocean, are drifted by every passing wind, allowing no foothold to vegetation; and clouds of sand, seen at the Highland Light, are lifted from this tract by gales to the height of three or four hundred feet.

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THE HILLOCKS OR MOUND-FORMATIONS OF SAN DIEGO, CALIFORNIA.[1]

BY G. W. BARNES, M.D.

THE surface geology of many sections of the Pacific slope is characterized by innumerable hillocks or small mound-like formations, either sparsely distributed or occupying quite densely areas of considerable extent. These formations, variable in size

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and structure in accordance with local conditions concerned in their production, exist in many parts of California and on the coast north of it, and are especially abundant and well defined in Southern California.

The following conclusions are based upon observations of them chiefly in the vicinity of San Diego:

In their most common type the mounds may be described as rounded eminences, or knolls, rising from one to four feet above the surrounding surface or the depressions between them, and ranging from ten to fifty feet in diameter. They are generally nearly circular and distinct, but are, in some instances, confluent or elongated. They are separated by wide and irregular areas or by narrow intervening depressions, the latter containing, in stony places, accumulations of cobblestones. They are confined to no geological structure or quality of soil, and are found on sloping lands, on the higher mesas and lower levels.

Any attempt at an explanation of their origin and the mode of their formation must be based upon the assumption that they are modern modifications of the earth's surface and are due to natural agencies; and evidences abound on every hand that the causes concerned in their production are still active in the formation of new and in the maintenance of the old ones; and hence in this vicinity they may be seen in all the stages of their growth, from small rudimentary cones to the fully developed knolls.

Several agencies acting successively or simultaneously have been concerned in these formations. Each mound marks a spot where formerly grew a shrub or cluster of shrubbery, which served to fix its location and which exercised an important influence in the successive stages of its development. The shrubs which seem to have been chiefly instrumental in these results are the *Rhus laurinâ*, the *Simmondsia californica* and the *Isomeris arborea*; the former undoubtedly having been principally instrumental in the creation of the more recent as well, perhaps, as the most ancient ones in this vicinity. These plants are fitted for the office they perform by the nature of their growth, which is in compact groups or clusters, with many stems starting from the earth near together, the branches and foliage forming a dense mass resting closely upon the ground, and with beds of massive roots; while the distribution of the groups is strikingly similar to that of the mounds in their typical form and arrangement.

FIG. 1.—Hillocks seen in outline near San Diego, Cal.

Dust set in motion and borne along by the winds is arrested by the shrub and, together with its fallen leaves, accumulate within and around it, and, as is seen in thousands of instances in this vicinity, an elevation of many inches is produced in this manner alone, in many cases covering the lower branches, and in case of the Simmondsia especially, nearly enveloping the whole plant. The gopher, subsisting upon roots and preferring for its operations the loose soil about them, is, in exceptional cases, an adjunct of the wind in heaping up material about the plant. Of the thousands of these clusters of shrubbery which have come under my observation, a very large proportion show unquestionable evidences of these agencies in elevations more or less marked about them, the surface portions of them at least being generally composed of a light loam of dust and decaying leaves. While the loose earth of which the deposit is composed is protected by the branches and foliage of the plant, the more solid earth beneath is also protected from the wash of rain by its massive roots, while all around erosion goes slowly on, facilitated by the peculiar susceptibility of the soil to wash, a quality familiar to the casual observer.

Instances doubtless exist in which the mounds have been more or less fully developed without the aid of those forces which elevate the earth above its original level, but the shrub and the rain wash have been constant factors.

In the course of time the plant dies—is smothered by the drift which nearly covers it, or is destroyed by the fires which annually sweep over extensive tracts of country. Thus deprived of its protection, the winds in turn, and the rains which fall upon it wear down the top of the loose deposit, and to some extent widen its base. While this is going on the surrounding earth, or interspaces, are being continually lowered by the action of water. The wash always being greater at the base than at its summit, its tendency is to perpetually maintain or increase the prominences.

The presence of beds of roots, well preserved as well as in the different stages of decay, within many of the more modern fully formed structures, upon the surfaces of which it is known from observation that no vegetation has grown for many years, is strongly suggestive of a relation between them of cause and effect. In the oldest ones all traces of the original roots have long since disappeared.

A well known effect of timber and shrubbery everywhere is to

impede the drainage of water which falls among it, and so these groups of plants serve to diffuse the currents—which would otherwise be concentrated into gulleys—whose meanderings may be traced in all directions among the mounds, thus conducing to the symmetry of their form and arrangement.

The influence of wash in these results is the most marked on moderate slopes, though sometimes seen on quite steep ones and on comparatively level places, but if upon levels, the latter are so situated as to receive the gathered waters from neighboring slopes. In a situation of this character near at hand the water, after traversing a surface of considerable extent among fully developed mounds, converges into a gully and a surplus flows off to the sea.

Evidences of the potent agency of the winds in results of greater magnitude than these need not be adduced. We need only refer to the sand dunes of Scotland and the shores of the American lakes. It is a matter of common observation here that during the prevalence of one of the "sand storms" of a few hours duration, which visits us once or twice annually, several inches of dust is deposited in places suited for its lodgment, yet the work here ascribed to the wind is mainly carried on by prevailing breezes from the ocean. In situations exposed to concen-

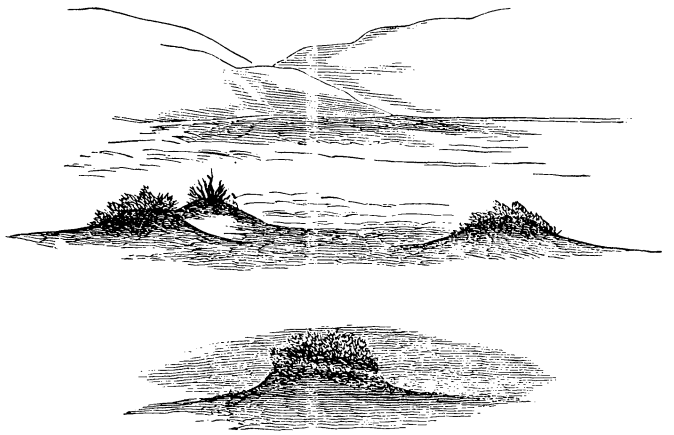

FIG. 2.—Simmondsia with earth heaped about them as in first stage of formation. From nature.

trated wind currents or their sweep over loose earth or traveled roads, the cones are the most sharply defined, showing that in such circumstances the work goes more rapidly on.

As a minor and exceptional agency I may mention that in the

later stages of the formations large excavations are sometimes made by the burrowing of animals, which are afterwards filled with débris, while the matter thus brought to the surface remains to augment the elevation. Hills formed in open spaces by animals do not constitute nuclei for mound-formation; composed as they are of a substratum in which no grass or other vegetable takes root and protects them from dissolution, they crumble away leaving but a bare and level spot.

To recapitulate; in the incipiency of the formation the eleva-

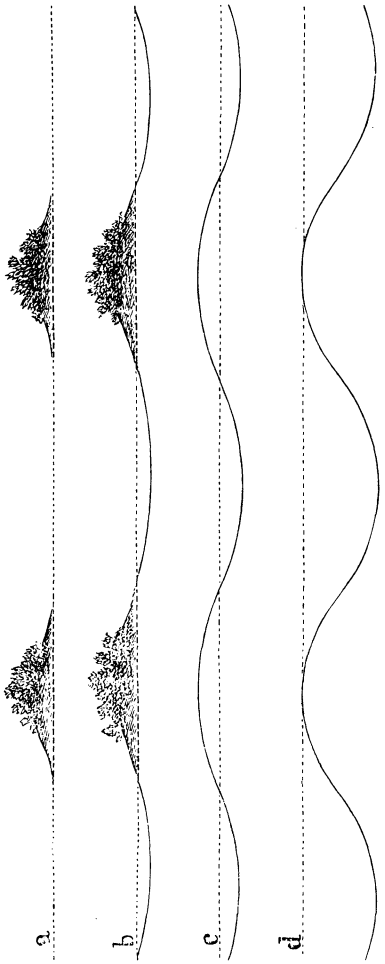

FIG. 3.—Ideal profiles of successive stages of the formations. The dotted lines represent the original surface of the earth.

tion is composed entirely of a deposit heaped often abruptly about the plant (Fig. 2, Fig. 3 *a*), but pretty soon the influence of erosion is manifest in the subsidence of the base.

Next the plant perishes, and, deprived of its protection, the summit is reduced and the base widened as it is lowered (Fig. 3 *b*) till finally a remnant of the deposit has become so assimilated and compact as to constitute a more permanent summit (Fig. 3 *c*), or it has totally disappeared, leaving the summit at or below its original base (Fig. 3 *d*).

Reasons for the appearance of these phenomena so exclusively on the Pacific slope and the arid plains of the West, are that the combination of causes resulting in their production there are seldom found elesewhere, to wit: the growth of shrubbery in compact clusters suitably distributed, with low and dense foliage, the presence of burrowing animals, the great susceptibility of the soil to wash and, I may add, the steady prevalence of winds from a single quarter, and the absence of forests which would otherwise influence winds and surface drainage.

Note.—Since the foregoing was written it has been suggested to me by a gentleman whose opinions have much weight, that the wind exercises an influence in excavating the earth around and between the shrubs of which the mounds are a sequence. While there is no evidence of such action in this vicinity, the explanation doubtless holds good in sections of the country in which a loose or sandy soil prevails. The mounds of this vicinity are found almost exclusively on the upland which, when dry, is quite firm and is not perceptibly acted on by the wind, yet sweeping over a considerable surface it gathers enough of soil, in time, to make large deposits about the shrubbery. Sandy soil is exceptional, and is found usually only in the valleys which are comparatively small in extent. In such situations the suitable vegetation does not so commonly exist, there is more protection from the winds, and the rains, generally light, are so readily absorbed that no surface-wash takes place.

It has also been suggested that pebbles and rocks form nuclei around which accumulations of soil remain and conduce to the production of the hillocks. It must be conceded that this is possible, and in certain qualities of soil and with certain kinds of rock quite probable. In this vicinity, however, in no stage of the process are the stones imbedded in the mounds found to be bare, or protruding, or to hinder in any manner the action of water on the soil; on the contrary, in a soil so easily disintegrated by water, the stones hold their positions by an uncertain tenure, and are so readily rolled from their cavities, as the earth is washed away from them, as to rather facilitate than retard the process of erosion.